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Comparative diagnostic performance of bronchoalveolar lavage and induced sputum in the evaluation of suspected lower respiratory tract infections

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Abstract

Background: Lower respiratory tract infections (LRTIs) remain a major cause of morbidity and mortality worldwide. Accurate identification of causative pathogens is crucial for effective management. Bronchoalveolar lavage (BAL) and induced sputum (IS) are commonly used diagnostic techniques, yet their comparative efficacy remains uncertain. **Aim:** To compare the diagnostic performance of induced sputum and BAL in patients with suspected LRTIs, assessing microbiological yield, diagnostic accuracy, turnaround time, and procedural safety.

Methods: This prospective observational study was conducted in the department of Pulmonary Medicine, SMS Medical College, Bengaluru, from November 2024 to August 2025. One hundred adult patients with clinical and radiological evidence of LRTI underwent both IS and BAL collection within 24 hours. Samples were analyzed for bacterial, fungal, and mycobacterial pathogens using standard stains, cultures, and molecular assays. Diagnostic accuracy indices were calculated using a composite reference standard.

Results: BAL demonstrated a higher microbiological yield (78%) than IS (64%) with significant sensitivity (91% vs 81%) and substantial agreement ($\kappa = 0.74$, $p < 0.001$). Minor bronchoscopy-related complications occurred in 6% of cases.

Conclusion: BAL provides superior diagnostic yield and sensitivity, while IS offers a safe, non-invasive, and reasonably accurate alternative for routine evaluation of LRTIs in resource-limited settings.

Key Words: Bronchoalveolar lavage; Induced sputum; Lower respiratory tract infection; Diagnostic yield; Microbiological analysis

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Introduction

Lower respiratory tract infections (LRTIs) remain a leading cause of morbidity and antimicrobial use, and accurate microbiological diagnosis is critical for targeted therapy and stewardship [1]. Induced sputum (IS) offers a non-invasive, low-cost route to sample lower airways but may be limited by variable quality and contamination from the upper tract, whereas bronchoalveolar lavage (BAL) is considered a more controlled, distal specimen obtained under bronchoscopy at higher procedural cost and risk [2]. Recent studies across diverse settings tuberculosis (TB), non-tuberculous mycobacterial pulmonary disease (NTM-PD), and community-acquired infections show mixed but complementary performance: some report superior BAL yields in smear-negative suspected TB, while others demonstrate high agreement between IS and BALF for common respiratory pathogens when molecular panels are used [1, 3].

The aim of the study is to compare the diagnostic performance of induced sputum versus bronchoalveolar lavage for suspected LRTIs, evaluating (i) microbiological yield (culture and molecular assays), (ii) sensitivity/specificity against a composite clinical–microbiological reference standard, (iii) time-to-result and impact on initial antimicrobial decisions, and (iv) safety and feasibility in routine practice. Evidence suggests BAL may add yield in smear-negative TB or NTM-PD, yet IS can approximate BAL performance for several viral and atypical bacterial pathogens and avoids bronchoscopy-related risks; a head-to-head evaluation tailored to our population and laboratory methods is therefore warranted [4].

Methods:

This prospective observational study was conducted in the department of Pulmonary Medicine, SMS Medical College and Hospital, Bengaluru, over a period of ten months from November 2024 to August 2025. Ethical approval was obtained from the Institutional Ethics Committee prior to initiation, and written informed consent was secured from all participants. Adult patients aged 18 years and above who presented with clinical and radiological suspicion of LRTI such as cough with sputum, fever, dyspnea, and new infiltrates on chest imaging were recruited consecutively. Exclusion criteria included patients on empirical antibiotics for more than five days, those with bleeding diathesis, severe hypoxemia ($SpO_2 < 85\%$ on room air), or refusal to

undergo bronchoscopy. A total of 100 participants meeting inclusion criteria were enrolled. Baseline demographic and clinical data, including age, sex, comorbidities, duration of illness, and radiological findings, were recorded using a pre-tested proforma.

All participants underwent IS collection followed by BAL within 24 hours. Sputum induction was performed using 3% hypertonic saline delivered via ultrasonic nebulizer under direct supervision in a negative-pressure room. Patients rinsed the mouth and gargled with sterile water before inhalation. The expectorated sputum was collected in sterile containers after ensuring adequate sample quality (Murray-Washington score ≥10 squamous cells and ≥25 neutrophils per low-power field). Fiberoptic bronchoscopy was then performed under local anesthesia with conscious sedation using intravenous midazolam and topical lignocaine. BAL was collected by instilling 100 mL sterile normal saline in 20 mL aliquots into the most affected segment, with gentle suction applied after each instillation. Samples were immediately transported to the microbiology laboratory for processing.

Microbiological analysis included Gram stain, Ziehl–Neelsen stain, fungal KOH mount, bacterial and fungal cultures, were used based on clinical suspicion. Diagnostic performance indices—sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated using a composite reference standard that combined clinical, radiological, and microbiological findings. Time to pathogen detection and antibiotic modification rates were recorded. Data were analyzed using SPSS version 21.0 (IBM Corp., Chicago, USA). Continuous variables were summarized as mean ± standard deviation, and categorical variables as frequencies and percentages. Agreement between IS and BAL results was assessed using the kappa statistic**.** A p-value < 0.05 was considered statistically significant. The study's primary outcome was the comparative diagnostic yield of BAL and IS, while secondary outcomes included procedure-related complications, sample adequacy, and turnaround time.

Results:

A total of 100 patients were enrolled, including 58 males and 42 females, with a mean age of 49.6 ± 14.2 years**.** The most common presenting symptoms were productive cough (88%), fever (76%), and dyspnea (62%). Radiological involvement was unilateral in 61% and bilateral in 39% of cases. Comorbidities included diabetes mellitus (32%), chronic obstructive pulmonary disease (24%), and bronchiectasis (15%). Microbiological positivity was achieved in 78% of BAL and 64% of IS samples (p = 0.032). Table 1 shows comparative yields. BAL demonstrated higher detection of *Klebsiella pneumoniae* (24%), *Pseudomonas aeruginosa* (18%), and *Mycobacterium tuberculosis* (10%), whereas IS was superior for *Streptococcus pneumoniae* and viral agents. When assessed against the composite reference standard, BAL showed sensitivity = 91%, specificity = 88%, PPV = 94%, NPV = 82%**,** while IS achieved sensitivity = 81%, specificity = 86%, PPV = 92%, NPV = 70%**.** The kappa coefficient (κ = 0.74, p < 0.001) indicated substantial agreement between the two methods. BAL had a mean turnaround time of 36 ± 8 hours**,** whereas IS required 30 ± 6 hours. Mild cough or transient hypoxia occurred in 6% during bronchoscopy but resolved spontaneously.

Discussion:

The population's mean age of 49.6 ± 14.2 years and male predominance (58 %) reflect a middle-aged cohort typical of adult LRTI studies; older age is a well-recognised risk factor for both incidence and severity of LRTIs. Abbadi et al. reported that males aged ≥70 years have higher incidence and worse outcomes from LRTIs [5]. This demographic profile underscores the vulnerability of middle-aged and older adults with respiratory symptoms and imaging changes. The presence of comorbidities diabetes mellitus in 32 % and COPD in 24 % of participants aligns with established evidence linking metabolic and chronic airway diseases to increased LRTI risk. Multiple published analyses have shown that comorbid diabetes and chronic lung disease significantly elevate the odds of acquiring and suffering severe LRTIs, through mechanisms such as compromised mucociliary clearance, altered immune responses, and chronic structural lung damage [6, 7]. Notably, our radiological finding of bilateral involvement in 39 % of cases corresponds with the generally worse prognosis seen when infection burden is greater and more diffuse, aligning with ICU-based cohort data identifying bilateral lung involvement as a marker of higher pathogen load and systemic illness [8].

Furthermore, the recruitment of consecutive adult patients with new infiltrates and symptoms provides a pragmatic real-world sample, improving external validity. The high proportion of participants with comorbid COPD (15 % bronchiectasis, plus 24% COPD) also means that structural lung disease was common—which is consistent with other studies showing a high burden of chronic airway disease among LRTI patients in tertiary referral settings [7]. These baseline characteristics thus suggest that our cohort was representative of a higher-risk group for LRTI, rather than an uncomplicated community sample, which may partly explain the relatively high microbiological yield shown later. The interplay of age, male sex, and comorbidity underlines the need to interpret diagnostic yields (IS vs BAL) within the context of elevated baseline risk and structural lung damage.

Table 1 reveals that the microbiological yield from BAL out-performed IS in our cohort (78% vs 64%, p = 0.032). This finding is consistent with several recent reports indicating that BAL, by virtue of sampling more distal lower-airway sites and reducing contamination, tends to yield higher pathogen detection rates than expectorated or induced sputum. For example, BAL has been highlighted as a commonly used procedure because it allows for targeted sampling of the lower respiratory tract with less microbial contamination from the upper aerodigestive tract [9]. Moreover, in patients with suspected pulmonary tuberculosis who were smear-negative, IS detected only ~38% of cases versus ~85% by BAL, underscoring the added advantage of BAL in certain high-risk scenarios [1]. In the setting of community-acquired pneumonia, the comparative study of IS and BALF (fluid) specimens likewise showed a higher yield by BALF samples [3]. The difference in yield supports our decision to include both culture and molecular assays and emphasises the role of BAL in enhancing diagnostic sensitivity. However, while the higher yield is favourable, the slightly longer turnaround time and resource-intensive nature of BAL must be weighed when interpreting our findings. In routine practice, the moderate yield of IS (64%) suggests it remains a valuable, less invasive alternative especially where bronchoscopy access is limited or risks are elevated.

BAL had a sensitivity of 91 % and specificity of 88 % in diagnosing suspected LRTIs, outperforming IS which showed sensitivity of 81 % and specificity of 86 %. These findings mirror recent meta-analytic data that report BAL sensitivity around 89 % and specificity around 90 % when applied in adult pneumonia settings [10]. The superiority of BAL in sensitivity suggests its advantage in capturing true positive cases, which is especially meaningful in high-risk or structurally damaged lungs where pathogen load may be low and contamination from upper airway sputum samples may reduce IS accuracy. As one large study noted, BAL allows for targeted sampling of the lower respiratory tract with less microbial contamination from the upper aerodigestive tract", improving its diagnostic reliability [9]. On the other hand, the fairly comparable specificity values (88 % vs 86 %) indicate that both methods perform reasonably well in ruling out non-infective cases, although our NPV for IS (70 %) was lower than for BAL (82 %), suggesting that a negative IS may not reliably exclude infection. Prior research in tuberculosis and other lower-tract infections supports the notion that IS may miss cases which are picked up by BAL, especially in smear-negative or atypical pathogen scenarios [1]. Overall, the diagnostic accuracy parameters from our study reinforce the argument that while IS remains a useful and less-invasive initial test, BAL should be considered when IS is negative or clinical suspicion remains high.

A κ-coefficient of 0.74 ($p < 0.001$), a mean turnaround time of 36 ± 8 hours for BAL versus 30 ± 6 hours for induced sputum (IS), and a 6 % minor complication rate associated with bronchoscopy offer meaningful insight into both the concordance and practical trade-offs of the two sampling methods. Firstly, the κ value of 0.74 indicates "substantial" agreement between BAL and IS, which is consistent with other recent work: one paediatric study of paired BALF and sputum found kappa values approaching 0.9 for key pathogens, signaling near-perfect concordance in certain settings [3]. Another adult study of fungal load in paired sputum and BAL specimens reported a κ of ~0.7 (95% CI 0.53–0.85), supporting good agreement [11]. These data suggest that IS though less invasive may provide information closely aligned with BAL in many cases. However, the remaining ~26% discordance highlights important cases in which BAL adds diagnostic value, especially when IS is negative but clinical suspicion remains high. Secondly, although IS had slightly faster turnaround time, the absolute difference (≈6 hours) may be less clinically meaningful in certain settings; yet the invasiveness and risks of bronchoscopy must be considered. Bronchoscopy-related minor complications (6%) are aligned with published reports of low but non-negligible risks associated with BAL [12]. In practice, this suggests that IS may serve as a viable first-line specimen in routine settings, reserving BAL for cases with high suspicion, negative IS results, or complex underlying disease. The high agreement parameter therefore supports a tiered diagnostic approach—starting with IS, and escalating to BAL when required balancing yield, safety and resource utilization.

Conclusion: The present study demonstrated that BAL offers a higher microbiological yield and diagnostic sensitivity than IS in suspected lower respiratory tract infections, particularly for bacterial and mycobacterial pathogens. However, substantial agreement between both techniques ($\kappa = 0.74$) indicates that IS remains a reliable, safe, and feasible alternative when bronchoscopy is contraindicated or unavailable. While BAL should be prioritized in smear-negative or complex cases requiring precise etiological confirmation, IS serves as an effective first-line diagnostic tool in routine practice, balancing diagnostic accuracy, turnaround time, patient safety, and resource efficiency in respiratory infection management.

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Table 1: Microbiological yield in % among the study members in the clinical specimen

Parameter	BAL	IS	p-value
Any pathogen detected	78	64	0.032
Bacterial	56	47	0.041
Fungal	8	6	0.212
Mycobacterial	10	6	0.089